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PERSONAL ENVIRONMENTAL PROTECTION FOR LUNAR AND OTHER SPACE MISSIONS

OTTO SCHUELLER

TECHNICAL DOCUMENTARY REPORT No. AMRL-TDR-64-18

MARCH 1964

BIOMEDICAL LABORATORY
AEROSPACE MEDICAL RESEARCH LABORATORIES
AEROSPACE MEDICAL DIVISION
AIR FORCE SYSTEMS COMMAND
WRIGHT-PATTERSON AIR FORCE BASE, OHIO

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NOTICES

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FOREWORD

This report was prepared by Mr. Otto Schueller, Altitude Protection Branch, Biomedical Laboratory, 6570th Aerospace Medical Research Laboratories, Wright-Patterson Air Force Base, Ohio, at the request of the Aerospace Medical Division, Air Force Systems Command, Brooks Air Force Base, Texas. This material was presented by Colonel J.M. Quashnock, Chief, Biomedical Laboratory, at a conference concerned with "Operation Moonflight" held 11 February 1963, at the USAF School of Aerospace Medicine, Brooks Air Force Base, Texas. The work reported herein was done in support of Project 6301, "Aerospace Systems Personnel Protection," Task 630104, "Space Protective Garments." This is a continuing project. The author acknowledges the assistance of Mr. D.R. Good, and Mr. W.H. McCandless, both of the Biomedical Laboratory.

ABSTRACT

This report concerns the area of personal environment protection. Some requirements for intravehicular and extravehicular personal protective assemblies for various lunar and other space missions are defined and the problems and criteria of mobility, pressurization, heat and humidity control are discussed. Some developmental possibilities and some areas requiring biomedical research are indicated. The necessity for an Aerospace Environment Test and Research Facility is shown and a design proposal, particularly adapted to the specific requirements of bioastronautics, is discussed.

PUBLICATION REVIEW

This technical documentary report is approved.

Wayne H. McCandless
WAYNE H. McCANDLESS
Technical Director
Biomedical Laboratory

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PERSONAL ENVIRONMENTAL PROTECTION FOR LUNAR AND OTHER SPACE MISSIONS

Otto Schueller

INTRODUCTION

Lunar missions will probably begin with surveillance flights around the moon to select and study suitable landing sites. The first landings may be undertaken during the lunar night because it would be easier to control the temperature than during the lunar day. During the first landings the astronauts may stay within the vehicle and use remotely controlled tools to make surface probes. However, they may have to go outside to do some repair or adjustment work on the vehicle after the landing impact. Lunar surface explorations will follow and stepwise be extended from a few hours to several days or weeks, during both the lunar night and the lunar day. Depending upon duration and purpose, the different missions will require different types of personal protective assemblies, ranging from soft anthropomorphic pressure suits to "hard" suits and capsule-type hybrid concepts. In designing these assemblies we should always consider not only the portion of the mission on the moon itself, but also the entire mission profile, including the launch preparations before take-off from the earth and the recovery operations after return. For example, the pressure suit for project Mercury had to be adapted for a special ventilation unit, which the astronaut could carry around with him so he would be comfortable during the launch preparations. Another example is the X-20 (Dyna-Soar) suit, which now has a built-in inflatable life vest in the coverall to keep the pilot floating, even with an open helmet visor, in case of an emergency landing in water.

All lunar missions, whatever their duration or purpose may be, will have one major phase in common, and that is the journey from earth to moon and back. For this, the astronaut will need first of all a comfortable intravehicular emergency suit.

Intravehicular Emergency Garment

The existing pressure suits are too uncomfortable for long trips of several days or more. A so-called "shirt-sleeve environment" within the vehicle would certainly be desirable. However, it would be unrealistic, particularly for military missions to count on an invulnerable submarine-like space vehicle that would make an emergency pressure suit unnecessary. It is probably more economical and feasible to concentrate our efforts on the development and improvement of existing pressure suit concepts to a point that the suit itself approaches the comfort of "shirt sleeves." Comfort is a paramount requirement, at least during a normal flight. In case of emergency some discomfort could be accepted. A comfortable emergency garment should be permeable to air to make it independent of a special ventilation system with umbilical tubes. It should be equipped with a soft hood instead of a heavy helmet. The development of a comfortable intravehicular emergency garment is more difficult than that of an extravehicular protective assembly. Some possibilities which may be of potential value to approach this goal are discussed under "Developmental Possibilities" (page 13).

Extravehicular Protective Assemblies

The design of extravehicular protective assemblies will depend upon duration and purpose of the mission. For periods of short duration up to a few hours, for example, to repair or make adjustments on the outside of the vehicle or for short surface investigations on the moon, the intravehicular emergency garment might be used, probably with an additional coverall for heat or cold protection.

For lunar surface explorations of longer duration, extended over several hours or days, a hard suit or capsule-type hybrid concept would offer higher safety and comfort and better protection against meteoroids and ionizing radiation. The intravehicular garment might be worn inside the hard suit or capsule-type hybrid as a kind of emergency underwear. A paramount requirement of extravehicular protective assemblies is mobility.

Mobility

During recent years the Aerospace Medical Research Laboratories has tried to replace the subjective evaluation of pressure suit mobility of the past with more reliable objective scientific test methods. At present we have four criteria for evaluating mobility of pressurized garment.

Mobility Range

The mobility range of the arms, for example, is measured by the arm-reach evaluator shown on figure 1. Measurements are taken while the suit is unpressurized and pressurized on the same test subject in steps of 15° of angle. The seat can be turned around the vertical axis so that a solid angle of almost a full sphere can be covered. A light signal is used as a control to assure that the back of the test subject is always in contact with the backrest of the seat.

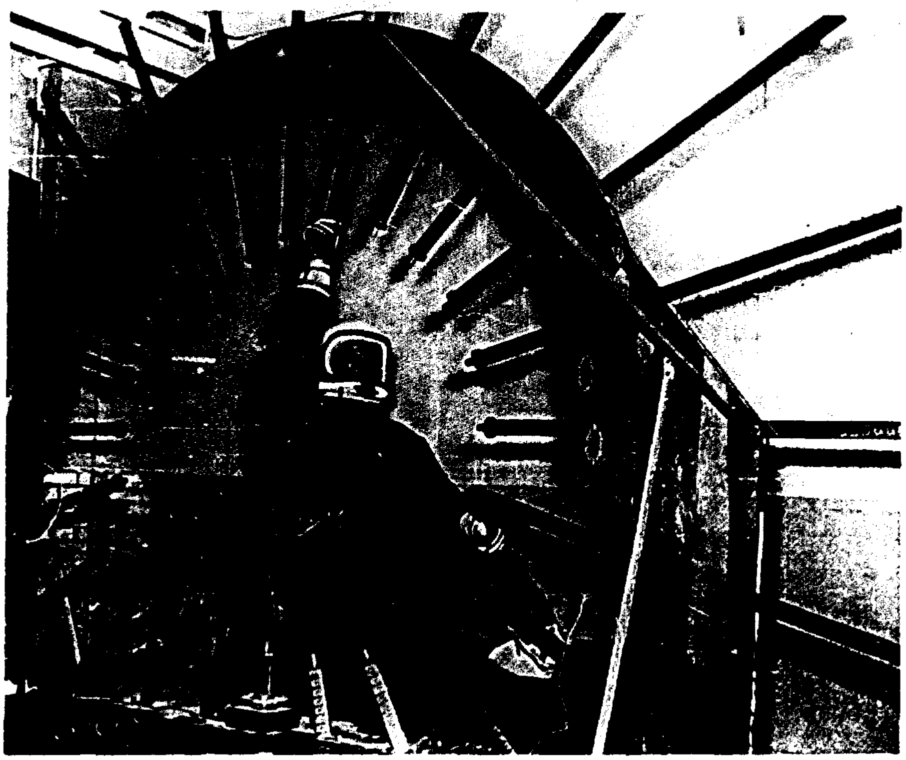


Figure 1. Arm-Reach Evaluator

Effort of Movement

The effort of joint movement is expressed as a bending moment in kg-cm (or foot-pounds) as a function of the angle of deflection. It is the product of the length of the forearm and the force required at its extremity to overcome the resistance to bending. This force is measured by inserting a metallic bellows between the palm of the hand and the inner side of the suit material. The interior of the bellows is communicated by tubing to a pressure gage calibrated to indicate force in kilograms or pounds exerted against the bellows. By applying an appropriate reduced pressure within the plexiglas joint test box shown in figure 2, the arm section of a pressure suit may be subjected to the same pressure difference and stresses that exist on the suit arm when attached to an inflated pressure suit. In the test box, two arm sections can be compared simultaneously, and with the latest modifications of the tester, both mechanical and pneumatic pressure suit elbow joints can be tested by applying the bending moment from the outside. The internally located bellows is not used in this case. The forearm is counterbalanced and both wrist and elbow moments can be measured by externally mounted torque wrenches. Additional instrumentation can be employed to indicate the moments on electrical meters and, if desired, these readings can be recorded. The test box has proved that subjective evaluation of joint mobility is absolutely unreliable and frequently in contradiction to the objective measurement.

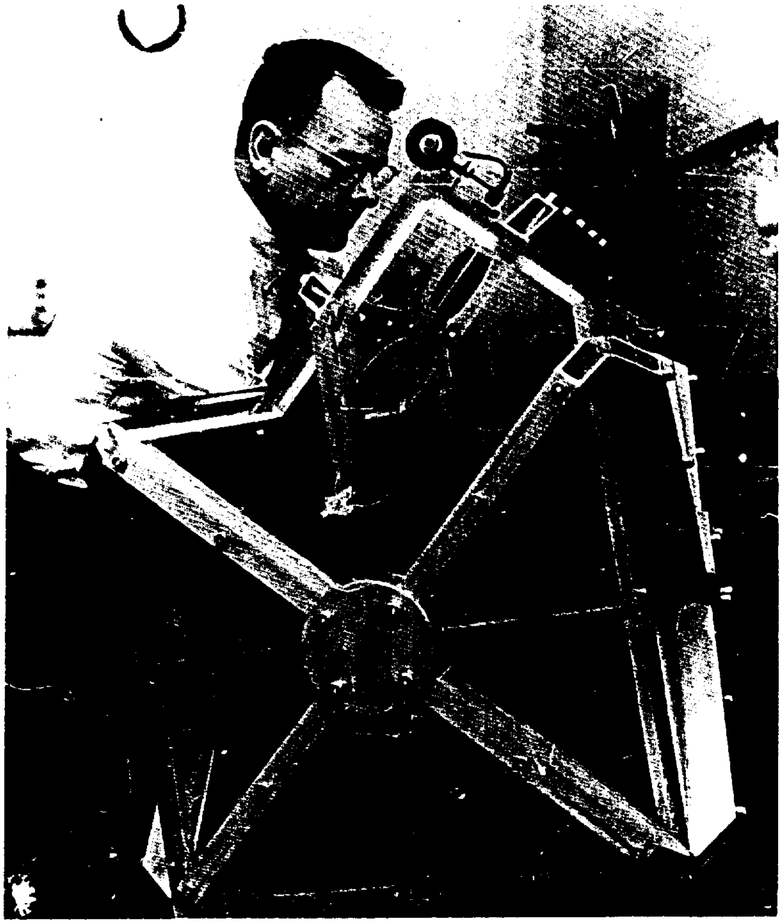


Figure 2. Plexiglas Joint Test Box

Energy Required to Maintain Position

Almost all of the existing joint designs have a certain equilibrium position into which they spring back if no force is applied. To hold these joints in a position other than the equilibrium position requires the physical expenditure of muscular energy. Over an extended period of time, this can be more tiring than to bring it in this position. The energy expended per unit time or power can be measured in kg-cm/sec (or foot-pounds per second). A universal joint using a sliding restraint system was developed within the Aerospace Medical Research Laboratories. It maintains almost any position by itself without requiring any energy, and it also requires very little effort to bend at any angle. A pressure suit to which this principle is applied is described in reference 3.

Directional Uniformity of Movement Effort

Some joint designs offer more resistance to bending in one direction than in another direction. With a shoulder and elbow joint combination of this kind, although the pilot may be able to reach a certain switch on the instrument panel, his movement automatically follows the path of lowest resistance. In this case the path would not be a straight line; the effect is very disturbing and could easily lead to error.

Until recently pressure suits were designed only for use inside aircraft. Therefore, arm and head mobility were among the major requirements. Pressurized assemblies for extravehicular use and for lunar surface exploration, of course, will require the development of additional criteria and test devices for evaluating suit characteristics for walking, kneeling, sitting, trunk bending, standing, climbing, crawling, etc.

Mobility of pressurized protective assemblies, in general, is dependent upon the pressure. The lower the pressure the better the mobility.

Pressurization

Because the human body cannot tolerate any appreciable degree of pressure differential, the air pressure in the lungs and the external pressure must be equal. There are two basic methods that can supply the required external pressure; namely, pneumatic and mechanical.

Pneumatic Pressurization

In pneumatic pressurization, the body is surrounded by a gas or liquid of the same pressure as the air pressure in the lungs. This principle is applied to full pressure suits and pressurized capsules and compartments. Usually the breathing gas, normally oxygen, is also used for pressurization and ventilation of the suit.

In the pressure suit (fig. 3) for the X-15, nitrogen is used for pressurization and ventilation of the suit, while oxygen of the same pressure is used for breathing through a mask within the helmet. Mr. Scott Crossfield, the X-15 contractor's test pilot, preferred an oxygen mask instead of a neck seal. The cryogenic nitrogen pressurization system for the cabin was used also for suit ventilation because of the possibility of fire hazards in the X-15. This suit is covered with a reflective coating. With improved mobility and a backpack air-conditioning unit, a suit of this kind could be used for short term extravehicular missions.

Mechanical Pressurization

The principle of applying mechanical pressure to the skin equal to the air pressure within the lungs was originally used on the capstan partial pressure suit developed by Aerospace Medical Research Laboratories (ref 2). The same principle was later applied to the Laboratories "get-me-down" suits utilizing bladders for pressurization (refs 6,7).

Figure 3. Full Pressure Suit

The main advantages of the original capstan partial pressure suit were that the garment did not need to be airtight, therefore, no ventilation system was necessary. These advantages were gradually lost as major areas of the body were covered with bladders. The get-me-down suit bladders almost surrounded the whole body to provide a more uniform pressurization of body parts. The capstan partial pressure suit has been generally abandoned except for use in the U-2 and other special missions.

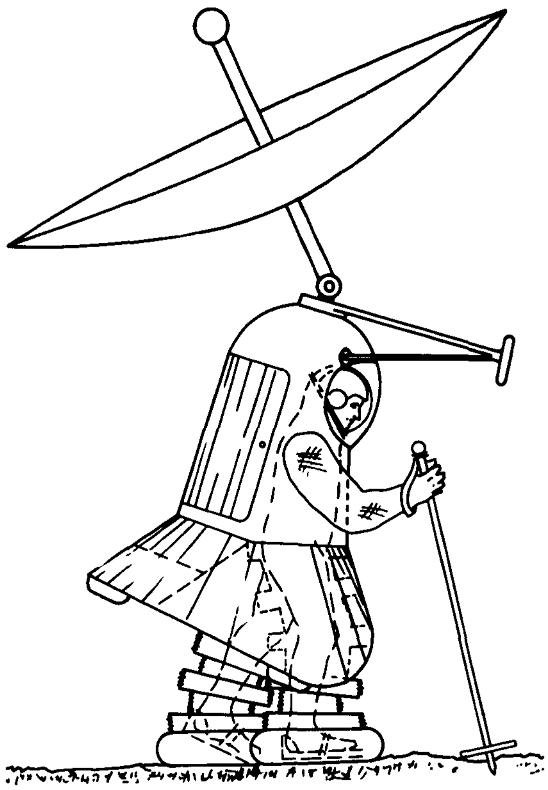
Mauch (ref 5), recognizing the potential advantage of mechanical pressurization, attempted to replace capstans and bladders by elastic but incompressible filling materials within a constant volume garment. He finally applied a collapsible multi- or microcell bladder, which was suggested by the Laboratories a few years ago. It is described in reference 4 and shown in figure 4 on the left side of a modified capstan partial pressure suit. A new idea in Mauch's conceptual design is that of cooling the body by controlled evaporation of water from the skin at low pressure by communicating the interior of the airtight garment through control valves with the vacuum in space. The suit is designed for short term extravehicular missions

Figure 4. Mechanical Pressure Suit

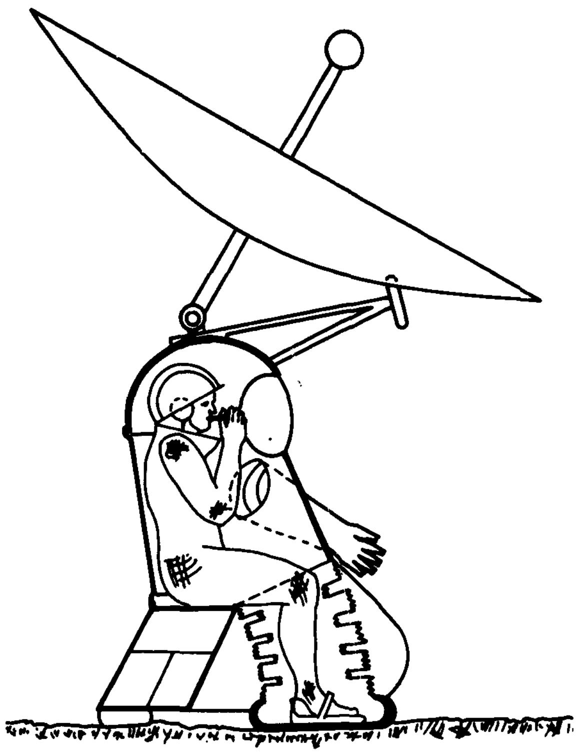
and potentially offers a higher safety factor than the full pressure suit. On ground level and at lower altitudes, however, the suit needs a supplementary system for proper ventilation.

Combination of Pneumatic with Mechanical Pressurization

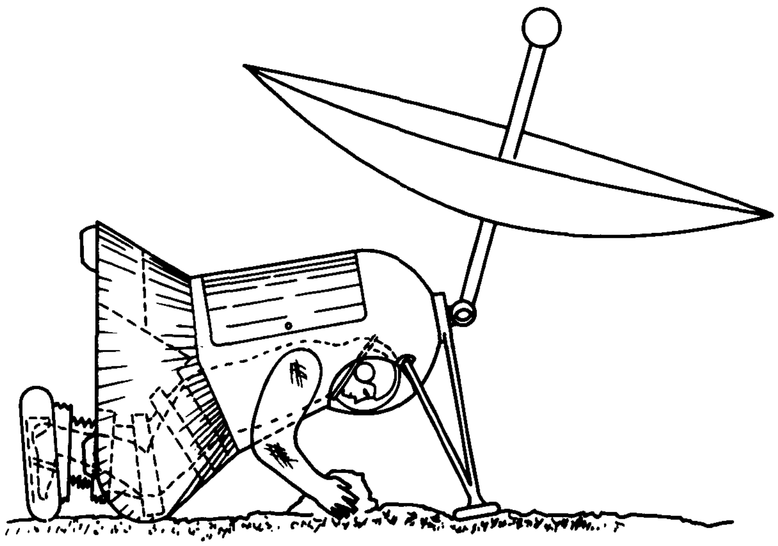
For many years the Air Force used this combination—a partial pressure suit for emergency protection of the airman in a pneumatically pressurized aircraft cabin (ref 1). Figure 5 shows a moon capsule suit designed for long term missions in which pneumatic and mechanical pressurization are combined. This combination offers the highest degree of comfort and safety and as long as the capsule is pressurized, the suit would remain unpressurized. In event of capsule decompression, the emergency mechanical pressure suit would be activated and the capsule would continue to offer protection against meteoroids and ionizing radiation. The heavier weight of this combination is not a limiting factor because the gravity on the moon is only one-sixth of that on earth. A capsule suit weighing 90 kg (200 pounds) on earth would weigh only



(Walking)



(Sitting)



(Kneeling)

Figure 5. Moon Capsule Suit

15 kg (33 pounds) on the moon. However, the inertia will not change, and the astronaut will have to adapt his motions to the strange effects of light weight with the same inertial effects during acceleration. Transportation of the heavier weight to the moon need not be a prohibitive factor, as the capsule could be an integrated part of the vehicle as indicated schematically in figure 6.

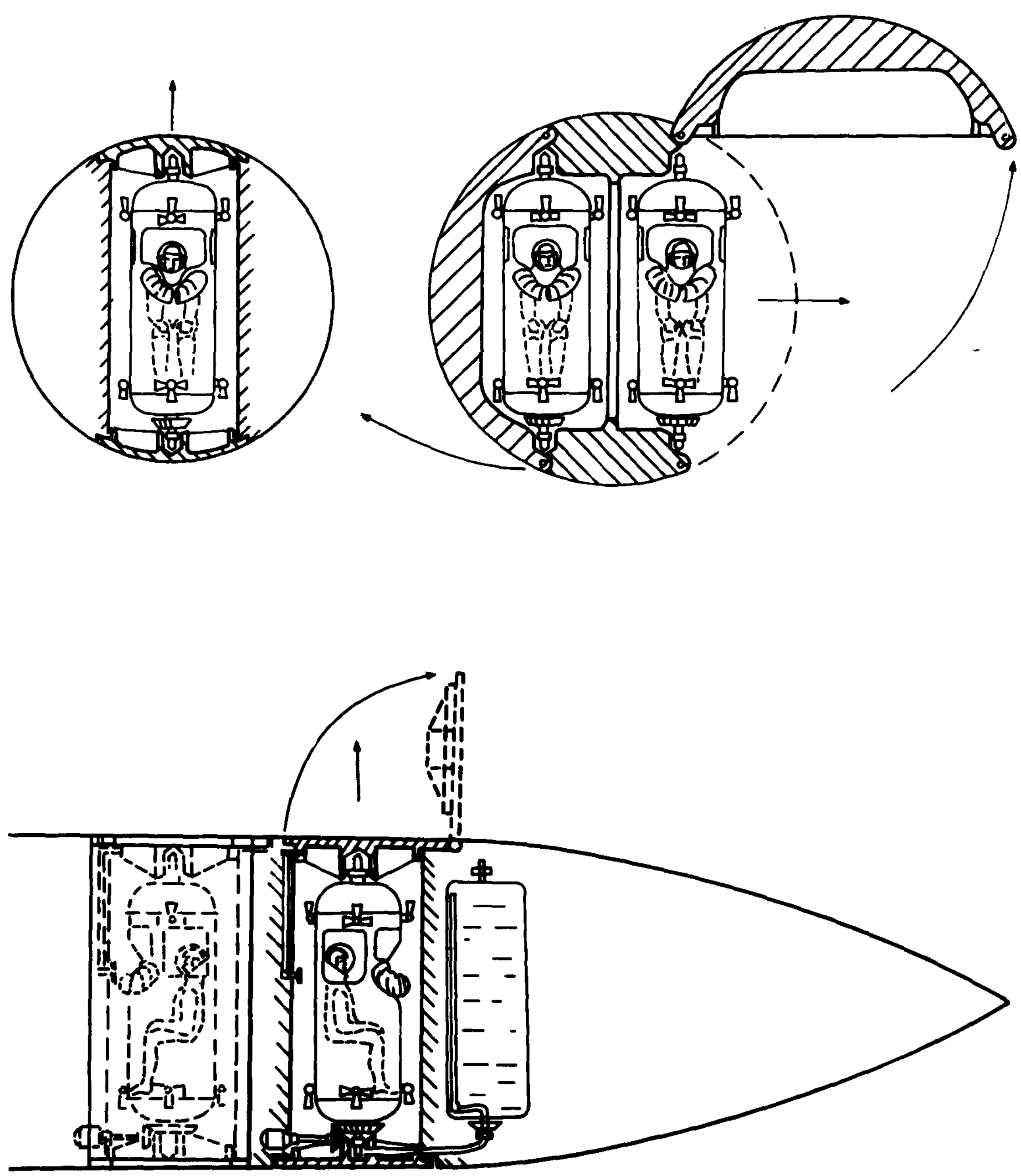


Figure 6. Capsule Integrated in Vehicle

Heat and Humidity Control

In the vacuum of space and on the moon there are two physical principles of heat exchange that can essentially be applied; they are heat exchange by radiation, and heat removal by evaporation of an expendable coolant. A third principle, conduction, accounts for heat exchange only where parts of a protective assembly are in contact with the lunar surface or with the vehicle. The application of these principles depends mainly on the duration and kind of mission. Humidity can be controlled by condensation or chemical absorption.

Dewar Principle and Expendable Coolant

For missions during the lunar night and for missions of relatively short duration during the lunar day, the simplest cooling method would be to design the capsule suit as a kind of large Dewar vessel and remove all excess heat by the evaporation of water from the skin or an expendable coolant. For example, the walls of the moon capsule suit (fig. 5) could be shielded by one or more sheets of highly reflective material, separated by the natural vacuum on the moon. This would make the assembly almost independent of the environment, even of the extreme changes between lunar day and night. The same principle can also be applied to soft anthropomorphic pressure suits. Evaporation of 1 liter of water at room temperature would be equivalent to the removal of about 585 kcal. If the water were taken in the form of ice supercooled by liquid nitrogen, this value could be increased to about 750 kcal. Table 1 shows the boiling temperature of water or the sublimation temperature of ice at various altitudes and pressures.

TABLE 1

BOILING TEMPERATURE OF WATER OR SUBLIMATION TEMPERATURE OF ICE AT VARIOUS ALTITUDES AND PRESSURES*

Altitude Feet	Pressure mm Hg	Boiling Temperature of Water or Sublimation Temperature of Ice	
		°C	°F
0	760	100	212
63,000	47	37	98.6
100,000	8.3	8.5	47.3
200,000	.17	-35	-31
300,000	7.6×10^{-4}	-76	-105
400,000	1.35×10^{-6}	-98.4	-145

*Based on Handbook of Chemistry and Physics, 40th Ed., 1958-1959, p. 2324, Editor Charles D. Hodgman, M.S.

Heat Pump with Radiator

For missions of longer duration, expendable coolant would be uneconomical. Instead, the heat could be removed by a heat pump to a radiator directed towards the black sky as suggested by Oberth (ref 8).

Spectrally Selective Coating with Adjustable Infrared Reflectors and Directed Radiation

Another way to eliminate, or at least minimize, the requirement for expendable coolant would be to use spectrally selective coatings in combination with adjustable infrared reflectors and directed radiation towards the sky. Figure 7 shows the relative absorption and emittance of a white titanium oxide coating that absorbs only about 20% of the direct solar radiation and reflects the remaining 80%. In regard to radiation in the long wave infrared, however, it behaves at room temperature almost like a perfect black body with a total hemispheric emissivity or absorptivity of about 95%. An application of this principle is shown in figures 8 and 9.

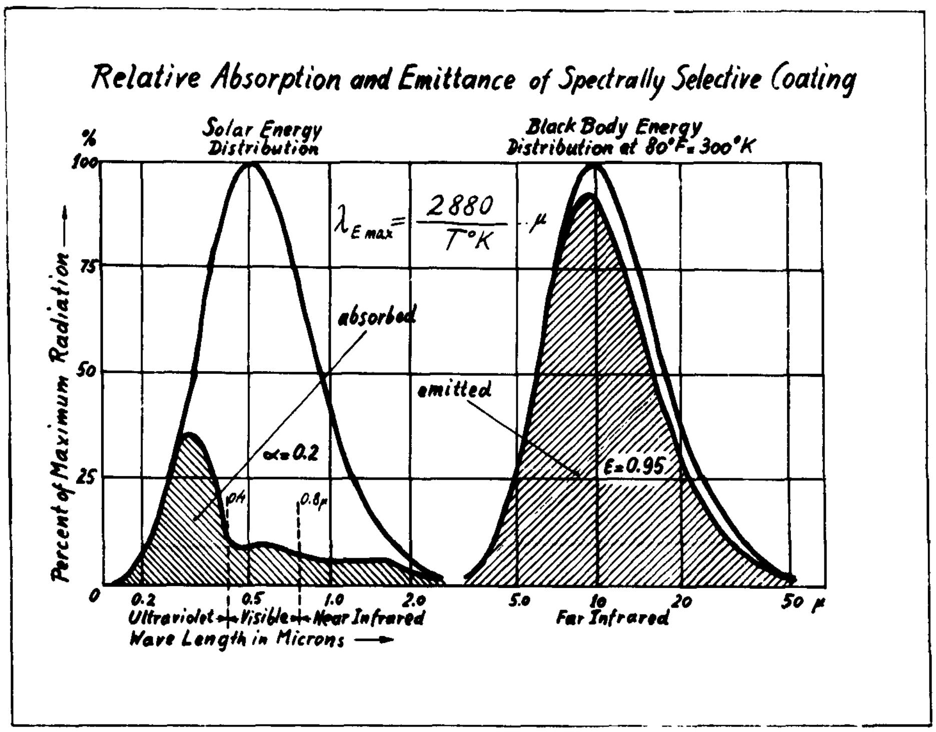


Figure 7. Relative Absorption and Emittance of Spectrally Selective Coating

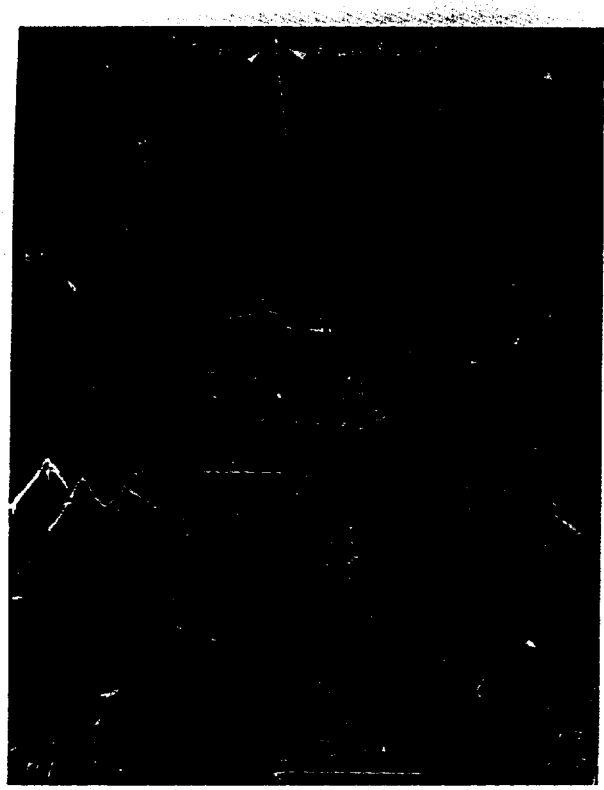


Figure 8 (left)

Moon Capsule with Adjustable Blinds

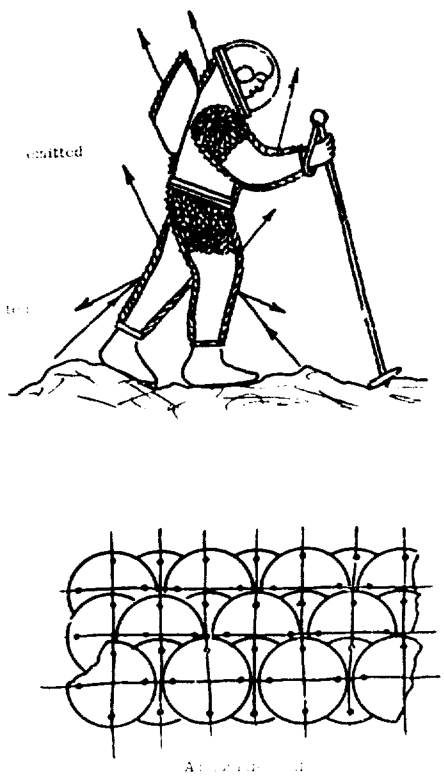


Figure 9 (right)

Space Suit with Adjustable Scale Armor

During the lunar day the blinds or scales are opened and the openings directed toward the sky. The major part of the lunar surface radiation is reflected back by the infrared reflecting blinds. The white coating of the capsule or suit, on the other hand, can emit heat through the channels between the blinds or scales toward the black sky and also reflect a large fraction of solar radiation partially incident through the slits.

During the lunar night the blinds or scales can be closed, thus preventing too large a heat loss from the white surface.

The design concepts shown in figures 5, 6, and 8 are offered as examples of a number of possibilities. The final and detailed design will depend upon the actual terrain conditions on the moon and the purpose of the mission. However, these figures illustrate the basic principles of pressure protection, heat and humidity control, and integration, and may be applied to any design concept, including the operator's compartment of a lunar surface vehicle.

Developmental Possibilities

As indicated previously, a common and paramount requirement of all lunar missions and also of other space missions, such as Military Test Space Station and Aerospace Plane, is a comfortable, intravehicular emergency garment. The need for such a garment has been emphasized repeatedly and promising proposals of potential value for the solution of this urgent and difficult problem were conceived within the Aerospace Medical Research Laboratories a number of years ago. Some of these ideas are as follow:

Collapsible Multi- or Microcell Bladders and Fabrics

Closed-cell sponge material and foam rubber have been tried several times during the past to substitute for vulnerable bladders and to provide a more uniform pressurization of the noncircular body parts in mechanical pressure suits. However, the expansion rates of these materials were too small and mobility was impaired by stiffness. It was suggested that the cells be filled with lower pressure so that they would collapse when exposed to normal pressure. The material would then possess a greatly increased rate of expansion and reduced stiffness as the individual cells could expand many times their initial volume before any tension would develop within the cell membrane. A garment made from such material would have a greatly enhanced mobility. This principle is applicable also to nonelastic plastic materials. Another suggestion was that the single closed cells or cell groups be separated by holes or pores to make the bladder permeable to air. In this manner, comfort would be increased by eliminating the necessity for a special ventilation system with umbilicals, and the greatest advantage of the original capstan partial pressure suit as a self-ventilating garment would be regained. As a further refinement, deviations from optimum pressure compensation caused by variations in body volume could be corrected by regulating the breathing pressure within certain limits. This would improve uniformity of pressurization and comfort and would also facilitate

breathing by a properly designed oxygen regulator. Another version was the suggestion that the principle of collapsible gas-filled cells be applied to a fabric woven of tubular threads. The fabric would be permeable to air as long as the gas-filled tubular threads were collapsed at normal atmospheric pressure. In case of decompression of the cabin and in the vacuum of space, the threads would expand and the fabric would become more or less airtight. The suit then could be inflated as a full pressure suit or the fabric could be applied in combination with perforated multicell bladders to control permeability to air at various pressures.

Low-Friction Lacings

Another design for an emergency pressure suit for spacecraft was proposed by Seeler (ref 10). It includes a partial-pressure-type suit, permeable to air, and a foldable soft hood, normally worn around the neck as a collar. Comfort of the suit should be achieved by almost frictionless lacings, which could be tightened automatically or by hand in case of decompression of the cabin. For uniform pressure distribution, multicell bladders are applied.

Biomedical Research Areas

The development of intra- and extravehicular protective assemblies could certainly be greatly advanced by systematic biomedical research. Some areas in which biomedical research would be desired are, for example:

Low Pressure Tolerance Levels

The great importance of mobility for extravehicular and lunar protective assemblies makes it desirable to keep the pressure in these garments as low as possible. A low pressure would also decrease stress on the material and reduce sealing and leakage problems. The importance of low pressure and the difficulty of these technical problems may best be recognized by considering the mechanical stresses of the suit material. In a medium-size suit pressurized with 5 psi, the force that would tend to elongate the suit is about 450 kg (1000 pounds). If the suit were pressurized with normal atmospheric pressure, this force would be about 1360 kg (3000 pounds). It would be of great value if tolerance levels for various durations (hours, days, weeks) of exposure to low pressure atmospheres of various compositions were clearly established as binding rules for all designers of protective assemblies.

Physiological Criteria for Effort of Movement and Maintaining Position

With the joint test box shown in figure 2, we can measure the effort of bending and maintaining position at various angles on elbow joints only. The requirement for mobility of the whole body in extravehicular and lunar assemblies and the complexity of these movements requires additional objective test methods and devices. It would be of great value, if objective physiological criteria for evaluating these efforts of mobility could be developed; for example, by measuring short-term metabolic rates (oxygen consumption, carbon dioxide production) during walking,

knee and trunk bending, etc. A reproducibility and accuracy of ± 15 to 20% would probably be sufficient for a crude evaluation.

Vacuum Exposure Tolerance of Skin Area Elements

The importance of comfort, particularly for intravehicular emergency suits, requires garments permeable to air and the elimination of a special ventilation system with umbilicals. In a garment permeable to air or with perforated bladders the skin would be partially exposed to the vacuum in event of decompression. For the development of comfortable garments, a systematic study would be of great value to define for various durations of exposure (minutes, hours, days) the maximum of the single area elements on various parts of the body that can be exposed to vacuum without excessive or irreversible damage to the skin or body. The dimensions of a given area element may also depend upon the ratio of uncovered to covered area and of the shape and configuration of the garment. It may be that for long-term exposure, the size of the pores in the fabric or bladder should not exceed the microscopic size of the tissue cells, while for short periods of time, surface elements in the square-millimeter or even square-inch range of certain body parts, could be exposed to vacuum without serious damage. The philosophy is that the astronaut's efficiency during a normal mission including survival during a possible emergency situation with some petechiae is preferred to a large loss of his efficiency by continuous discomfort during the entire mission.

Vacuum exposure of the skin and body has not yet been adequately exploited. A great problem, for example, is cooling of gloves without reducing the astronaut's sense of feeling, touch, and mobility. Oberth (ref 8) suggested that the hands might eventually be adapted to vacuum exposure by training. This may well be possible for a short exposure time. Nevertheless, tolerance levels certainly exist for various size areas of different body parts as a function of the duration of exposure. A systematic study of this problem could be performed, for example, simply by sealing various samples of garments and perforated bladders onto various parts of the body under an evacuated bell jar. For simulating the actual conditions in space, the test subject should be in an altitude chamber at a pressure equivalent to the anticipated suit pressure of, for example, 3.5 and 5 psia, and the bell jars completely evacuated.

Cooling by Controlled Evaporation of Water from the Skin at Low Pressures

A systematic study of the principle suggested by Mauch (ref 5) extended over various periods of time at various low pressures would be very valuable. A crude evaluation of the feasibility and efficiency of this principle could be made by comparing the original partial pressure suit with a full pressure suit without ventilation, under the same thermal conditions in an altitude chamber.

Aerospace Environment Test and Reseach Facility

For the development and testing of personal protective assemblies for lunar and other space missions a test and research facility is necessary to simulate the high vacuum and thermal radiation environments in space and on the moon.

A design for such a facility has been proposed. It includes a high-vacuum chamber with cryogenically cooled black walls, a solar simulator, infrared radiators, and a biomedical safety lock. The facility would simulate the conditions of lunar day and lunar night. The facility is described and illustrated in detail in another report (ref 9).

CONCLUSIONS AND RECOMMENDATIONS

1. A most important requirement common to all lunar missions and other aerospace missions, such as Aerospace Plane and Military Test Space Station is, a comfortable intravehicular emergency pressure suit, which should be permeable to air, independent of a ventilation system and equipped with a soft hood instead of or in addition to a heavy helmet. Some developmental possibilities for such a garment are fabrics composed of gas-filled tubular threads, collapsible perforated multi- or microcell bladders, and low-friction lacings.

2. The design of extravehicular assemblies depends upon duration and purpose of mission. For short-term extravehicular missions, the intravehicular emergency suit could be used, probably with an additional coverall. For long-term extravehicular missions hard suits and capsule-type hybrid concepts, combining pneumatic with mechanical pressurization, offer a higher degree of safety and comfort. Beyond safety and reliability, mobility is of the upmost importance.

3. Additional criteria and test devices are required for objective evaluation of mobility in walking, kneeling, sitting, crawling, climbing, standing, etc.

4. Heat control can be obtained by the Dewar principle and expendable coolant, heat pump with radiator, and spectrally selective coatings in combination with infrared reflectors and directed radiation; humidity control can be effected by condensation and chemical absorption.

5. Some areas requiring biomedical research are low-pressure tolerance levels, objective physiological criteria for efforts of moving and maintaining position, vacuum exposure tolerances of skin area elements, and cooling by controlled evaporation of water from the skin at low pressures.

6. An Aerospace Environment Test and Research Facility, particularly designed and adapted to meet the specific requirements of bioastronautics, is necessary for the development and testing of personal protective assemblies for lunar and other space missions.

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